Measurement of the $\bar{B}_s^0$ meson Lifetime using Semileptonic Decay with Single Lepton Datasets in CDF Run II

(CDF 7683)

Blessing Jul-07 2005 @ B meeting
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— Blessing —

1. Analysis overview
2. Questions and answers
3. Plots and numbers to bless

Introduction & analysis outline

We measure the $\bar{B}_s^0$ meson lifetime with 8 GeV lepton (e, μ) trigger datasets.
(Currently we use only the decay chain $\bar{B}_s^0 \to \ell^- \bar{\nu} D_s^+ X$, $D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$.)

1. Select a lepton (e or μ) from 8 GeV lepton datasets
2. Reconstruct $D_s^+ \to \phi\pi^+, \phi \to K^+K^-$ signal around the lepton
3. Calculate $\bar{B}_s^0$ pseudo-proper decay time
4. Correct missing momentum (K factor)
5. Model combinatorial background shape
6. Determine resolution scale factor
7. Estimate physics backgrounds
   - Prompt charm background
   - Bottom background
8. Extract the lifetimes using unbinned likelihood fit
9. Estimate systematic uncertainties

Questions & Answers

— 16 questions —

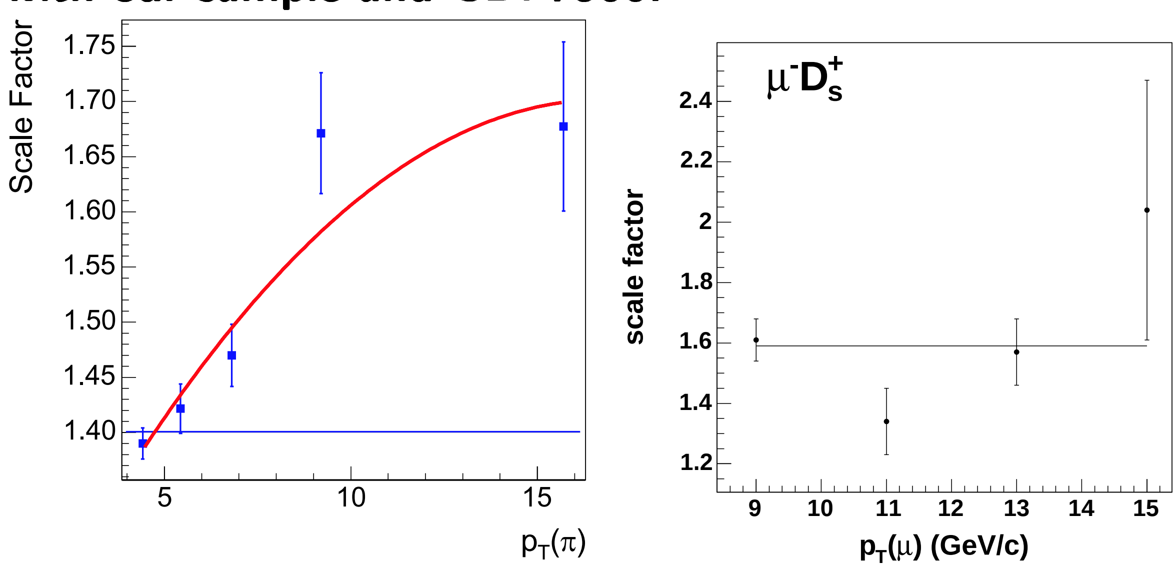
Question 1 - 2

Q1 : Do you consider including $D_s^+ \to K^*K$ and 3π modes?

A1 : We may add these modes in future, but not in this time.

Q2 : Calculate the resolution scale factor using the procedure in CDF note 7500

A2 : Due to running out of time, we could not do detailed study for this issue.
So we just compare $p_T(\mu)$ dependence of the scale factor with our sample and CDF7500.



The value of the scale factor is consistent in the region $p_T(\mu) > 8$ GeV$/c$.

Question 3

Q3 : What is the effect of a non-zero value of $\Delta\Gamma_s$ on this measurement?

Q3-1 : Define precisely what you measure

A3-1 : In the semileptonic decay, with the non-zero delta-gamma the decay rate is described as:

$$P(t) = \frac{1}{\frac{1}{\Gamma_S} + \frac{1}{\Gamma_L}}(e^{-\Gamma_S t} + e^{-\Gamma_L t}).$$

We fit it with single exponential, so the measured lifetime is written as,

$$\tau(\text{single-fit}) = \frac{1}{\Gamma}\frac{1 + (\frac{\Delta\Gamma}{2\Gamma})^2}{1 - (\frac{\Delta\Gamma}{2\Gamma})^2},$$

where $\Gamma = (\Gamma_S + \Gamma_L)/2$, $\Delta\Gamma = \Gamma_S - \Gamma_L$.
(see Eur. Phys. Jour. C 8 381 for detail)

Question 3 (cont'd)

Q3-2 :Can you perform the fit with two exponentials instead of one, with the difference given by the World Average $\Delta\Gamma_s$? As a systematic you can change $\Delta\Gamma_s$ within the errors.

**A3-2 : We tried the two-exponential fit with the following $\Delta\Gamma/\Gamma$ taken from HFAG web page.
with the $\Delta\Gamma/\Gamma = 0.33^{+0.09}_{-0.11}$, we obtain**

$$\tau_S = 1/\Gamma_S = 336.6 \ \mu\text{m}$$
$$\tau_L = 1/\Gamma_L = 469.6 \ \mu\text{m}$$

And the $1/\Gamma = 392.2 \ \mu$m.

**If we assume $\Delta\Gamma/\Gamma = 0$, the $1/\Gamma = 414.0 \ \mu$m.
It says that $\Delta\Gamma/\Gamma = 0.33$ is not a negligible amount.
However in this time we want to bless single exponential fit result assuming $\Delta\Gamma = 0$, same as several other $\bar{B}^0_s$ lifetime measurements.**

Question 4

Q4 :What is the effect of the recently discovered $D_{sJ}^{+} \to D_s^{(*)+}\pi^0$ decays on your measurement?
These processes are not taken into account in the simulation and can be expected to affect the K factor distribution.

A4 : We looked the EvtGen decay table and checked that these processes are already included.

——— EvtGen decay table ———

`# this is the DsJ with` $J^P = 0^+$

```
Decay D_s0*+
1.0000 D_s+ pi0 PHSP;
Enddecay
```

`# this is the DsJ with` $J^P = 1^+$

```
Decay D'_s1+
1.0000 D_s*+ pi0 PHSP;
Enddecay
```

Question 4 (cont'd)

Q4-2 : Effect of the uncertainty on D_{sJ}^{+} Branching fractions

A4-2 : For the $\bar{B}_s^0 \to \ell^- \bar{\nu} D_{sJ}^{+} \to \ell^- \bar{\nu} D_s^+ X$,
it is part of the signal and affects the K distribution, but it is included under the uncertainty in $f^{**} = 0.36 \pm 0.12$.

For the physics background $B^-/\bar{B}^0 \to D_{sJ}^+ X$,
it is not just only through DsJ, but also, and mainly, from D_s^+ and D_s^{*+}, so it does not really matter if D_s^+ is from D_s^+, D_s^{*+}, or D_{sJ}^+. because inclusive $B \to D_s^+ X$ branching ratio is measured well.
Certainly we do not know how much non-strange vs strange B, and in the end they are covered under a large uncertainty in $f_s/(f_u + f_d)$.

Question 5

Q5 : Once you have developed a complete procedure to evaluate the $\bar{B}_s^0$ lifetime and uncertainties I would like to know how the central value and errors differ between that and a procedure more like that used for the Bd and Bu modes, before we can proceed to blessing a $\tau(\bar{B}_s^0)/\tau(\bar{B}^0)$ ratio.

A5: The main change from previous $\tau(B^-)/\tau(\bar{B}^0)$ analysis is switching the MC decayer from QQ to EvtGen. Since it may mostly affect to the K factor distributions, I examine the change of K factor from QQ to EvtGen, and fit the $B^-/\bar{B}^0$ lifetimes again, and compare the results.

with QQ :

$$\begin{aligned} c\tau(B^-) &= 495.6 \pm 8.6\mu\mathrm{m} \\ c\tau(\bar{B}^0) &= 441.5 \pm 10.9\mu\mathrm{m} \end{aligned}$$

with EvtGen :

$$\begin{aligned} c\tau(B^-) &= 496.2 \pm 8.5\mu\mathrm{m} \\ c\tau(\bar{B}^0) &= 442.3 \pm 10.9\mu\mathrm{m} \end{aligned}$$

Question 6

Q6 : Don't you think that phi mass window cut ($|M(KK) - 1019.5| < 7$MeV) is pretty tight.
In other analyses we use 10MeV (semileptonic) or 7-8MeV (hadronic).

A6: Since we do not use the SVT, our signal purity is not as good as the ones with the SVT datasets.
So we need to reduce backgrounds in other ways.
The phi mass cut is one of a good handle for it.
Using 7 MeV window greatly improve the signal purity.

7 MeV window :

$$f_{\text{sig}} = 0.503 \pm 0.011$$
$$S/\sqrt{S+B} = 24.1 \pm 0.8$$

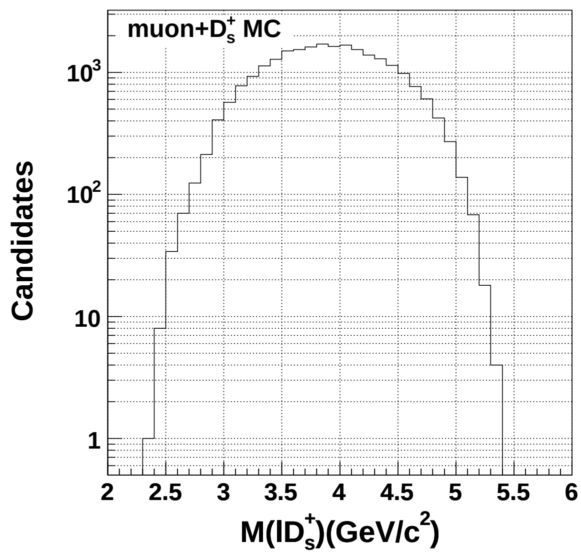
10 MeV window :

$$f_{\text{sig}} = 0.439 \pm 0.012$$
$$S/\sqrt{S+B} = 23.5 \pm 0.9$$

Question 7

Q7 : I would cut on M(l+Ds) $<$ 5.3 and not 5.4 GeV. There is not signal at all about 5.3 GeV, and you are accepting some possible additional background.

A7 : Since the M(l+Ds) have correlation to the K factor, we cut on the M(l+Ds) keeping 100% efficiency to the signal.



Indeed there is not much events in 5.3 $<$ M(l+Ds) $<$ 5.4 GeV.
Following numbers are comparison of the signal fraction under two cut values.
$M(l+Ds) < 5.4$**GeV...**$f_{\textbf{sig}} = 0.503 \pm 0.011$
$M(l+Ds) < 5.3$**GeV...**$f_{\textbf{sig}} = 0.504 \pm 0.011$
So the effect is negligible. But we take the 5.4 GeV just to make sure to have 100 % efficiency.

Question 8

Q8 : I would expect the bottom background fraction of muons and electrons to be roughly the same, but you have a factor two somehow missing in electron, any idea?.

A8 : We think this should be mainly from acceptance of lepton ID cuts for the bottom background events.
(The signal fraction is almost same in muon and electron, but the acceptance for combinatorial background will not be same for physics backgrounds.)
Here is a comparison of muon and electron, and electron w/o electron ID cuts.

Sample	fraction (%)			
	$\bar{B}_s^0$ semileptonic	$B \to DD_sX$	$B \to D_sD_sX$	$\bar{B}_s^0 \to \tau D_sX$
μ	93.4	4.2	1.0	1.4
e	96.6	2.2	0.3	0.9
e (no e ID)	95.0	3.5	0.4	1.2

After disabling the electron ID, agreement with muon goes better way. There are still slightly a difference. We do not fully understand the reason, but possible reason may be slight differences of branching fractions, or effect of electron clustering.

Question 9 (by Guillelmo)

Q9 : If we focus on the muon channel for bottom BG, I would expect more background ($\sim \times 2$) from $B^-/\bar{B}^0 \to DD_sX$ processes. (this is just my guess using my already SVT bias MC sample and cutting in Pt>8GeV). The tau and $\bar{B}^0_s \to D_sD_s$ backgrounds in the muon channel make sense to me.

A9 : We checked the procedure again (Guillelmo checked our procedure, too), but we could not find any mistakes with it. There are some differences between our and Guillelmo's MC samples, e.g. SVT bias, $p_T(B)$ and f^{**} tuning, and kinematic cuts. We think some of them is giving the difference.

Question 10 - 11

Q10 : On the charm background fraction fit, the probability of the electron fit is almost 0, do you have any comment on it?

A10 : We do not fully understand about it. But since the electron ID is more complicated than the muon ID, there could be some quantities difficult to reproduce in the MC (e.g. isolation, kinematics...).

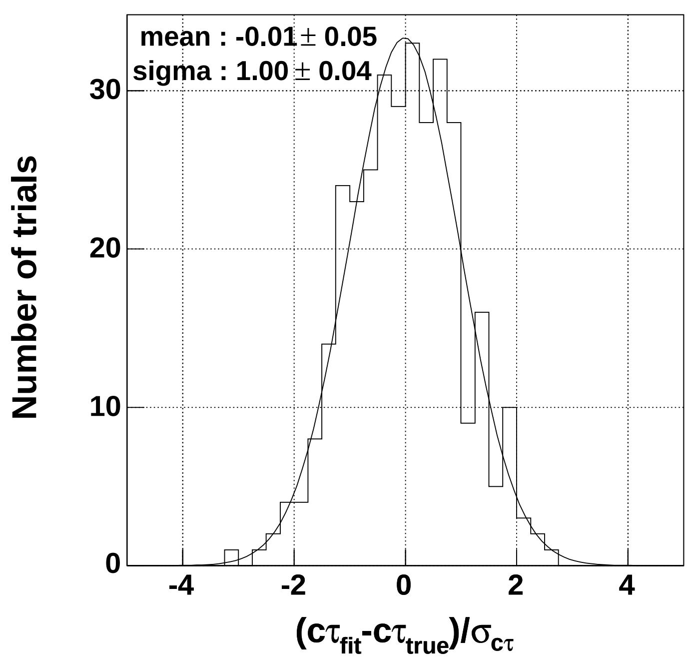
Q11 : Is there any way to reduce the prompt charm systematic.
Could the amount of prompt charm contribution be constrained from other sources.
For the differential charm cross section results could be multiplied by the lepton and phi pi branching ratios to estimate the level of background.

A11 : We think it is difficult to reduce the prompt charm systematics with current statistics.
If we want to use prompt charm cross section result, we will need to study acceptance of trigger & offline cuts and measuring lepton fake rate, etc.
Anyway the charm fraction uncertainty is from statistical error, so it will be reduced in future when we get more statistics.

Question 12

Q12 : Perform sanity checks with your lifetime fit.

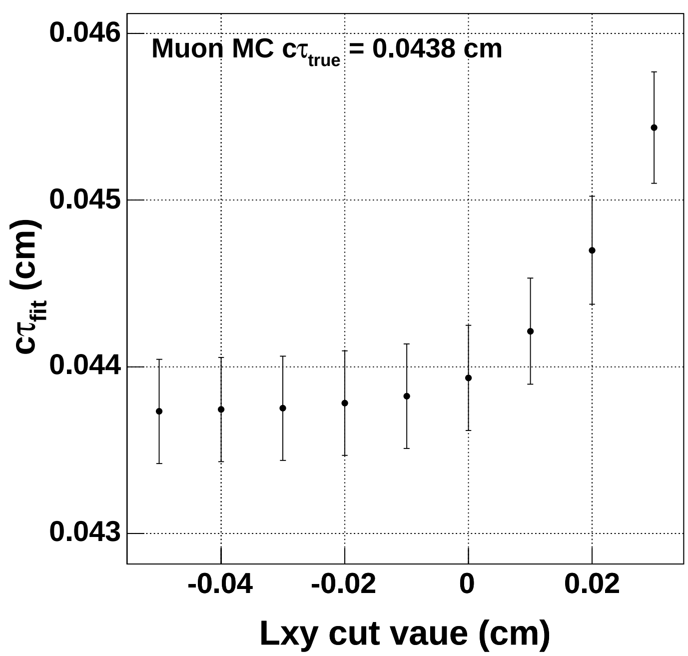
A12 : We perform the check using toy MC sample. We generate 1000 samples. Each sample contains 4000 events of $\bar{B}_s^0$ semileptonic MC events, and background events which corresponds to signal fraction about 0.5 . The plots below show the pull distribution for 1000 trials. The mean is consistent with 0, and the sigma is 1. It indicates the fitter works correctly.



Question 13

Q13 : You cut on Lxy(D)>0. It's a very loose cut, but I'd like to see how much bias you introduce with this cut (if any). Could you make the fit on realistic MC versus the Lxy cut to see the bias dependence?.

A13 : As you can see the bias from Lxy>0 cut is about 2 μm, and it is already included in the systematics.



Question 14

Q14 : Does the prompt charm fraction have even larger errors from systematicuncertainties in the prompt fraction fit. For instance, you need as include the $\bar{B}_s^0$ lifetime.

A14 : We examine systematics to fc measurement from the input $\bar{B}_s^0$ lifetime used for B component template. Currently we use $c\tau(\bar{B}_s^0) = 438\ \mu$m. We switch the MC input $c\tau(\bar{B}_s^0)$ 414 μm (our results). Then make a B component template and fit the f_c again.

$$\text{input } c\tau(\bar{B}_s^0) = 438\ \mu\text{m} \quad \begin{aligned} f_c &= 3.6 \pm 4.5\%\ (\mu) \\ f_c &= 0.0 \pm 7.1\%\ (e) \end{aligned}$$

$$\text{input } c\tau(\bar{B}_s^0) = 414\ \mu\text{m} \quad \begin{aligned} f_c &= 1.4 \pm 4.5\%\ (\mu) \\ f_c &= 0.0 \pm 7.3\%\ (e) \end{aligned}$$

For the muon, there is about -2% of negative shift of f_c observed.
At the systematics evaluation, we change the muon f_c as 0 - 8.1 % (the lower fc value is physicslly limited at $f_c = 0$.)
So the negative fc shift from $c\tau(\bar{B}_s^0)$ change cannot drag down the f_c lower limit. Eventually it doesn't change the systematic uncertainty from f_c to the $c\tau(\bar{B}_s^0)$.

Question 14 (cont'd)

Q14 : Does the prompt charm fraction have even larger errors from systematicuncertainties in the prompt fraction fit.

A14 (cont'd) : We also check effect from ct_2 resolution scale factor.
Measured scale factor for ct_2 is 1.46. We change it in a region 1.2 - 1.7 . The change of fc is less than 1%.
If we quadratically add this f_c uncertainty to the statistical uncertainty, total uncertainty changes from ± 4.9 to ± 5.0 % for muon, ± 7.1 to ± 7.2 % for electron.
The 0.1 % of fc uncertainty change is actually give negligible effect to the systematics on the $c\tau(\bar{B}_s^0)$.

Question 15

Q15 : How much $b\bar{b}$ background is there?

A15 : We estimate amount of the bbbar background with Pythia + QQ parametric simulation.
In the sample we found the fraction to be,

$$b\bar{b} : \bar{B}_s^0 \text{ semileptonic} = 12 : 1202 = 1.0 \pm 0.3\%$$

It affects to the $f_b' = N_b/N_{D_s^+}$ about 0.8 %, and eventually give effect to lifetime about 1.1 μm, which is quite small.

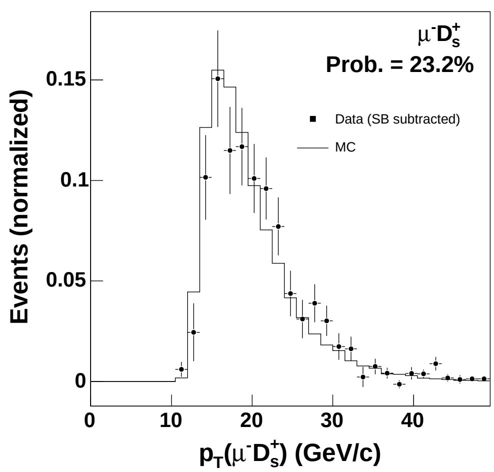
Question 16

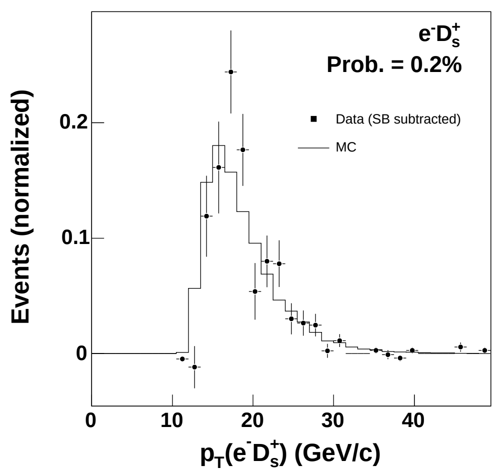
Q16 : Please give the probability for data/MC agreement in the pt spectrum for the region of interest.

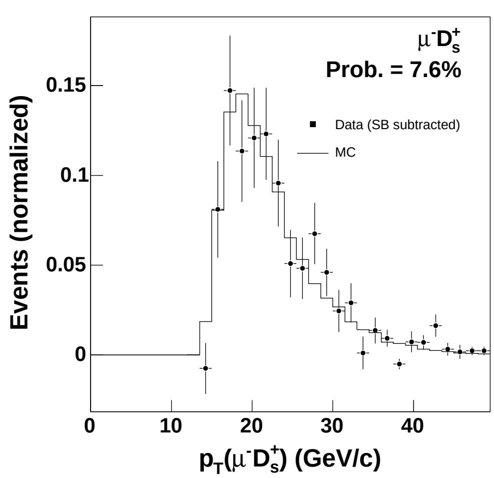
A16 : These are the comparison for lepton+D_s^+ transverse momenta.

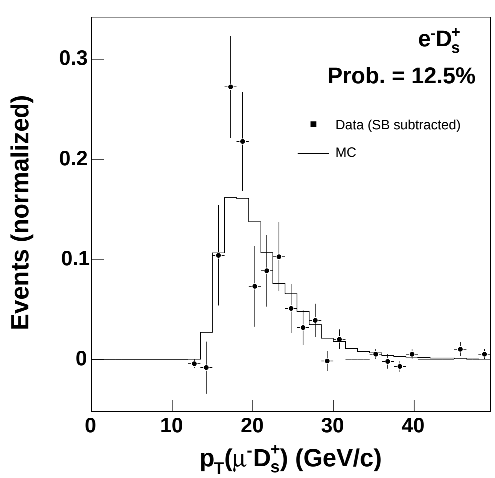
Upper plots : $p_T(\ell) > 8$ GeV

Lower plots : $p_T(\ell) > 10$ GeV (avoid trigger turn-on effects)





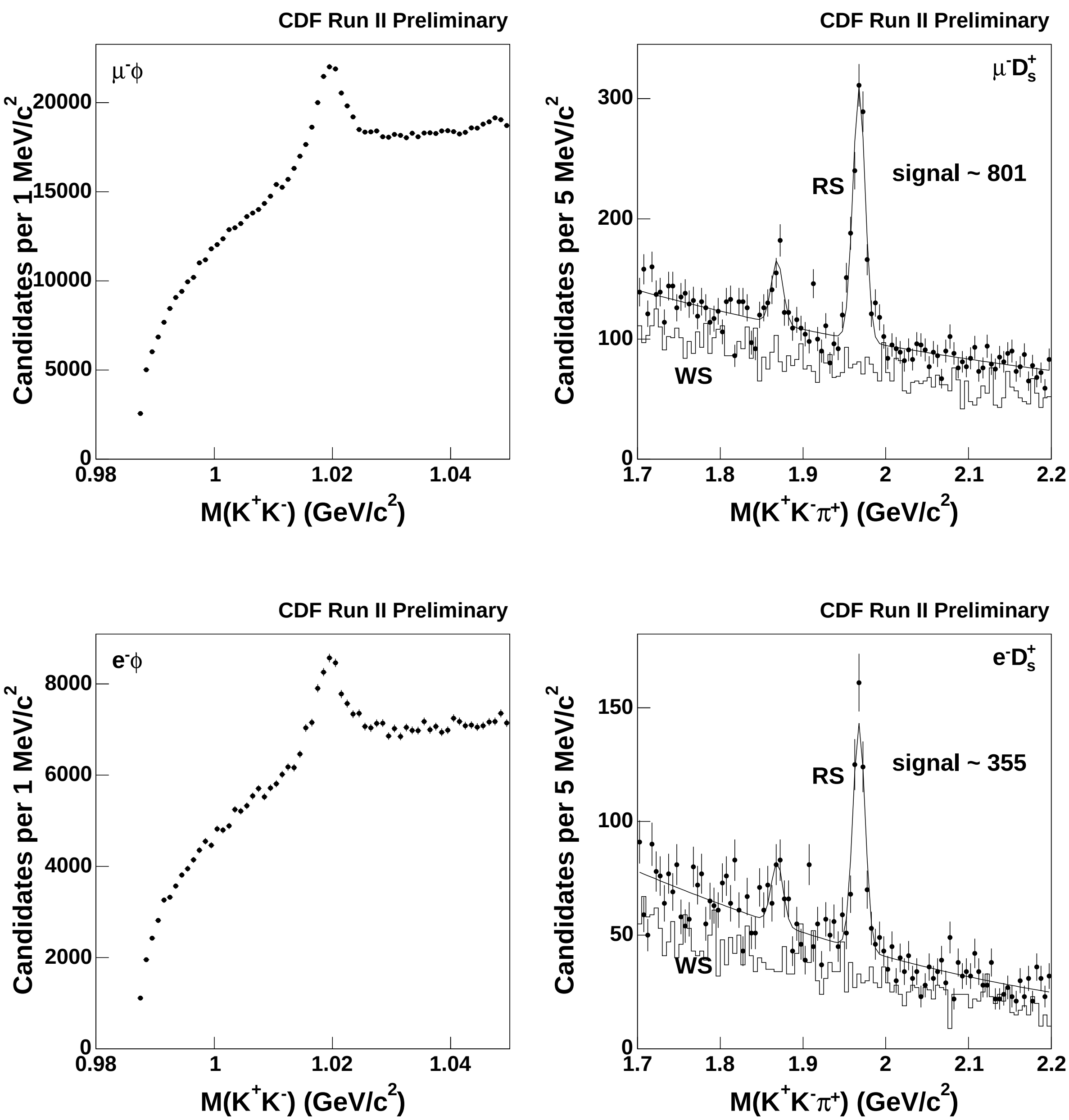




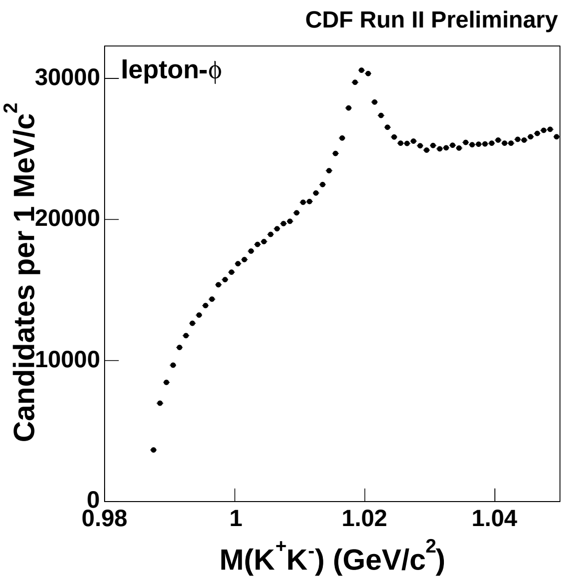
Plots and numbers we ask to bless

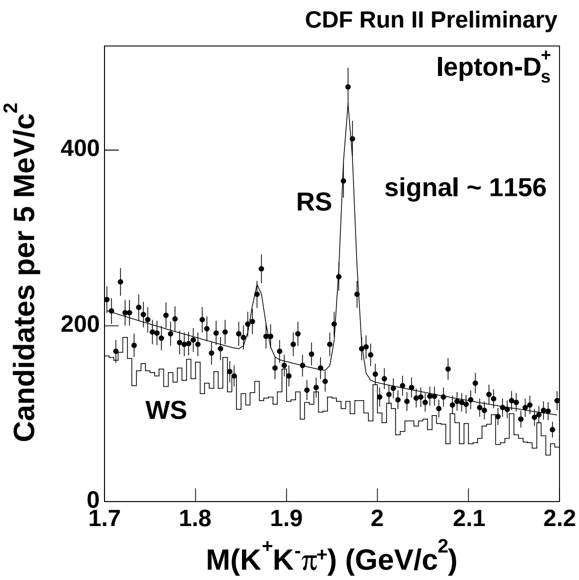
— 14 slides —

$\ell^- \phi$, $\ell^- D_s^+$ mass plots



$\ell^- \phi$, $\ell^- D_s^+$ mass plots

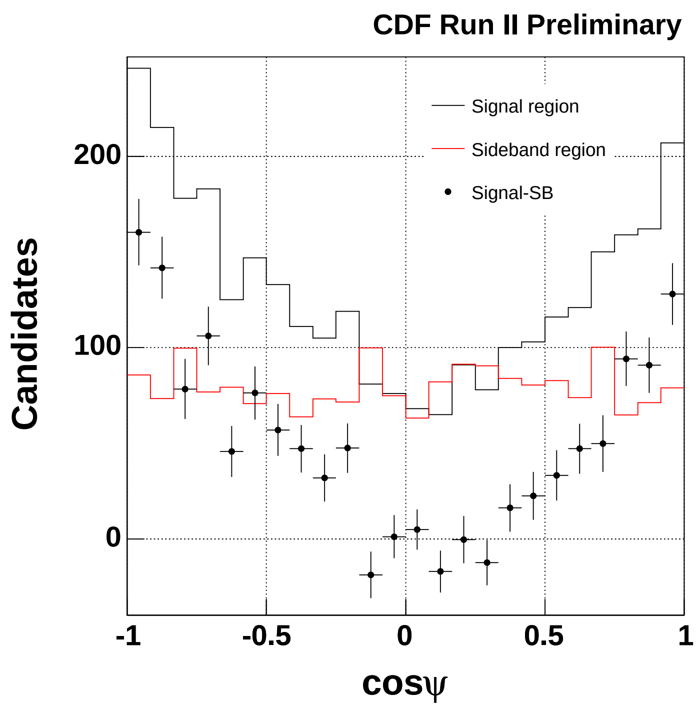


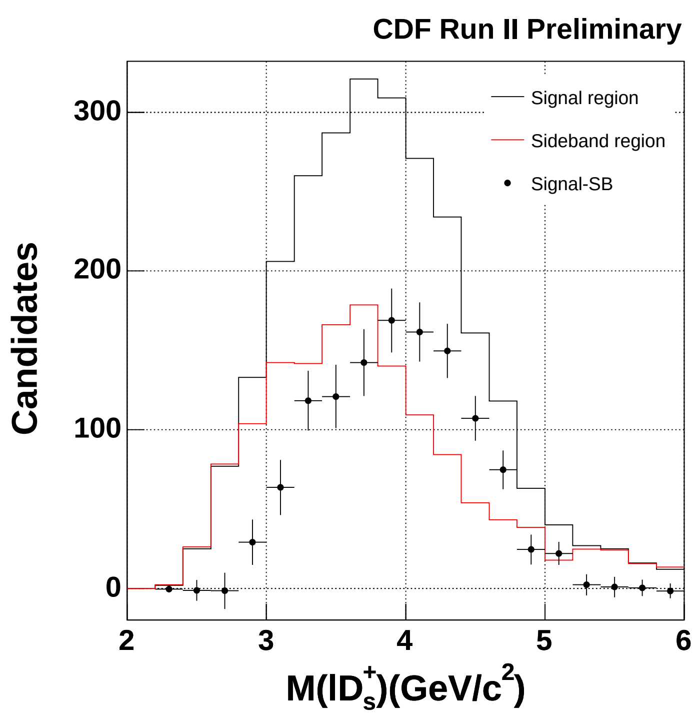


Sample	$M(K^+K^-\pi^+)$ range (MeV/c^2)	Events	D_s^+ signal fraction
$\mu^- D_s^+$ signal	1947.5 - 1987.5	1591	0.503 $\pm$ 0.014
$\mu^- D_s^+$ sideband	1900-1930, 2005-2035	1181	
$e^- D_s^+$ signal	1947.5 - 1987.5	706	0.503 $\pm$ 0.021
$e^- D_s^+$ sideband	1900-1930, 2005-2035	535	

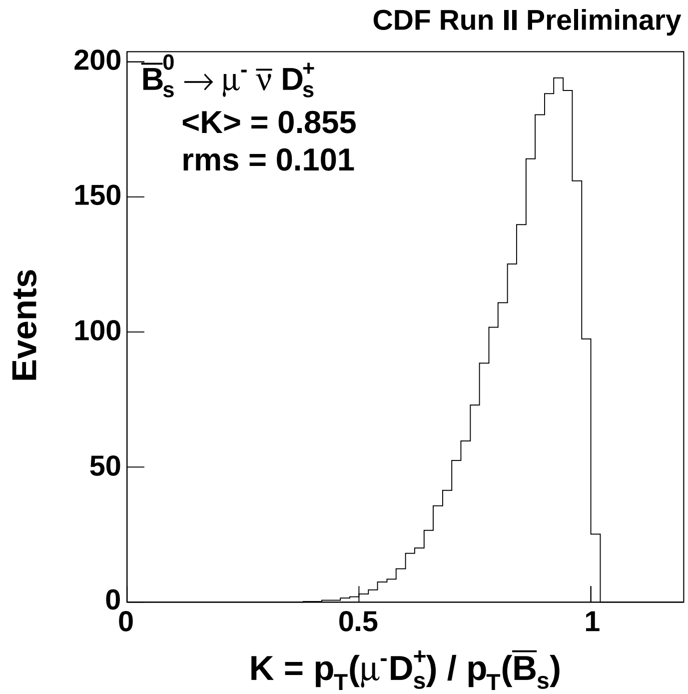
Summary of signal, sideband region definitions and yields.

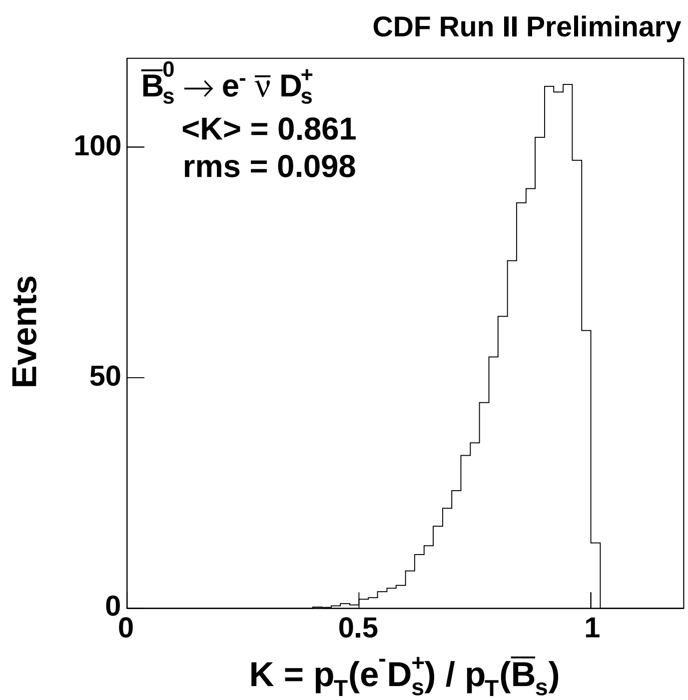
Helicity angle and $M(\ell^- D_s^+)$ distributions



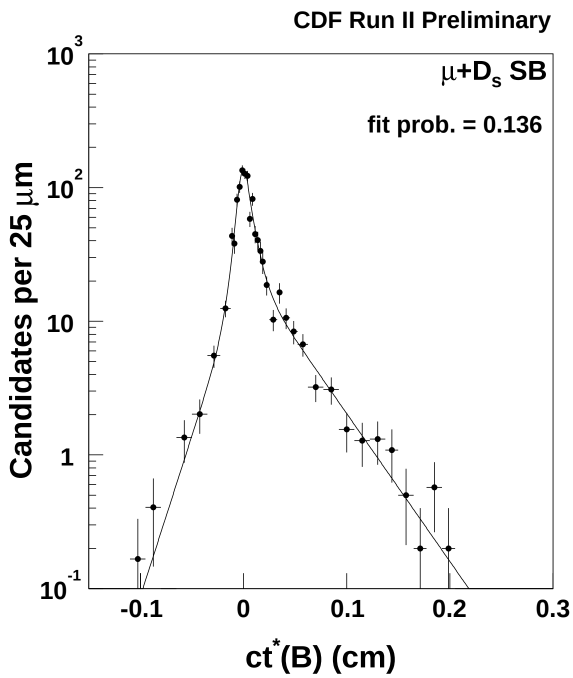


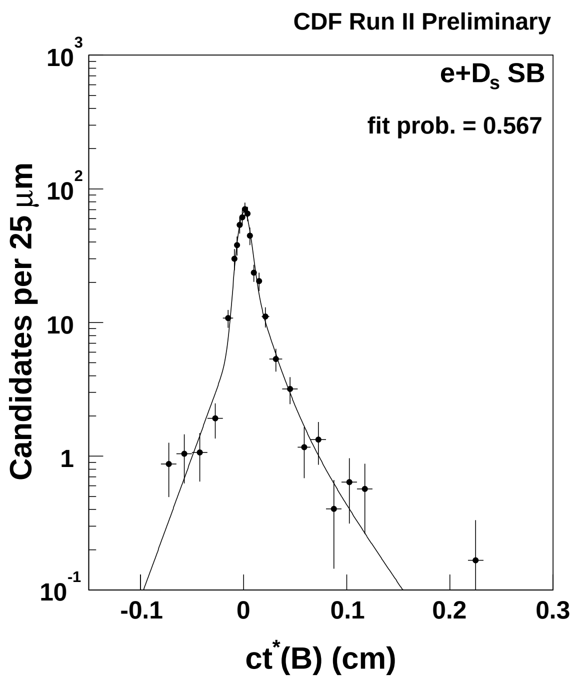
K factor distributions



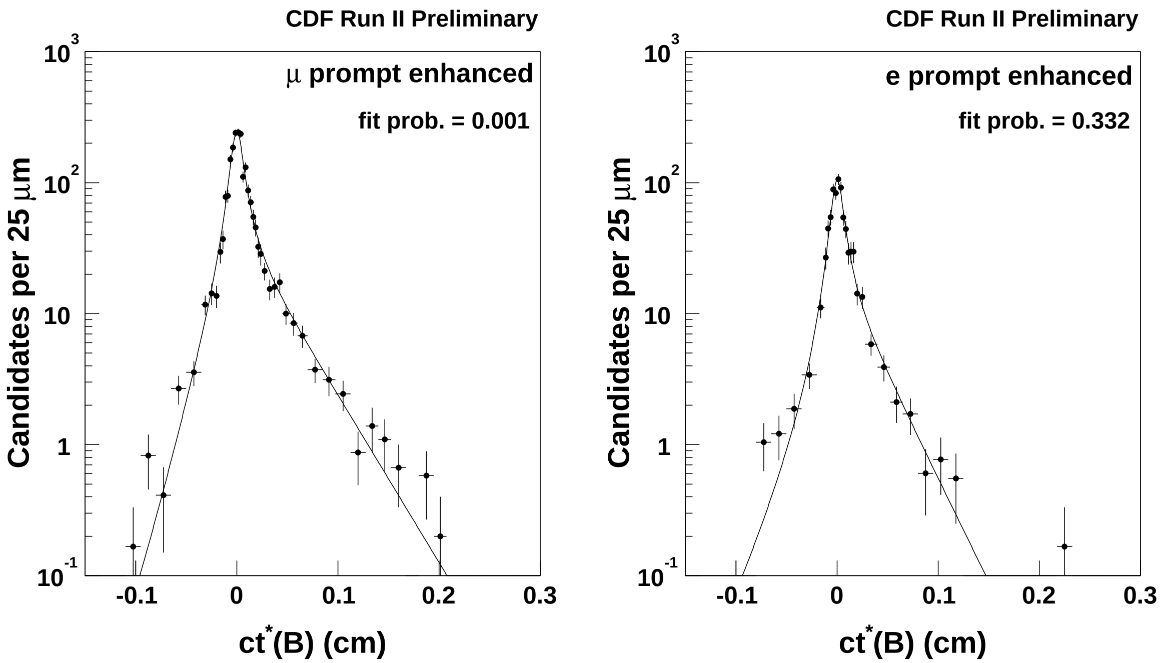


ct^* shape of sideband events



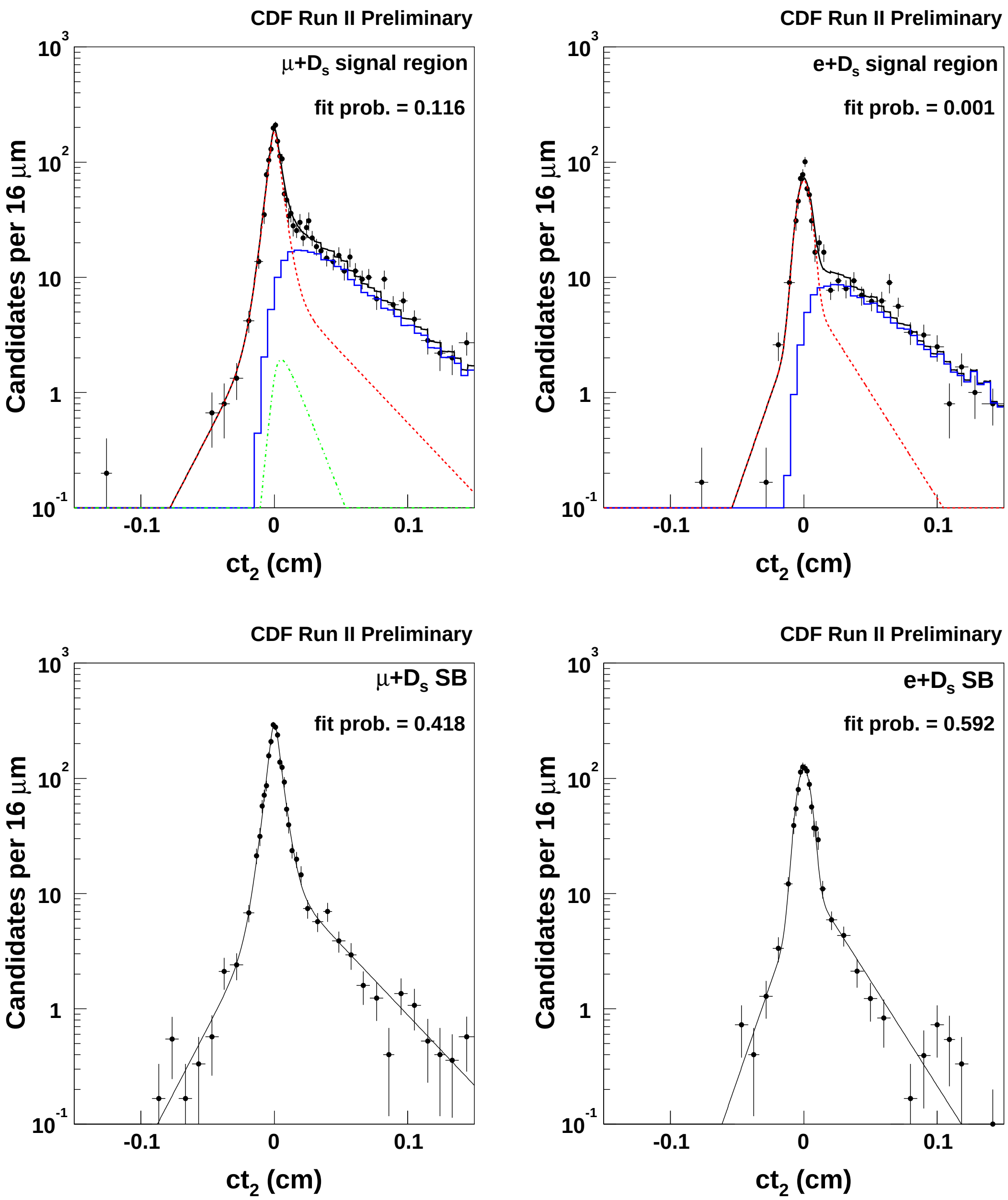


Resolution scale factor



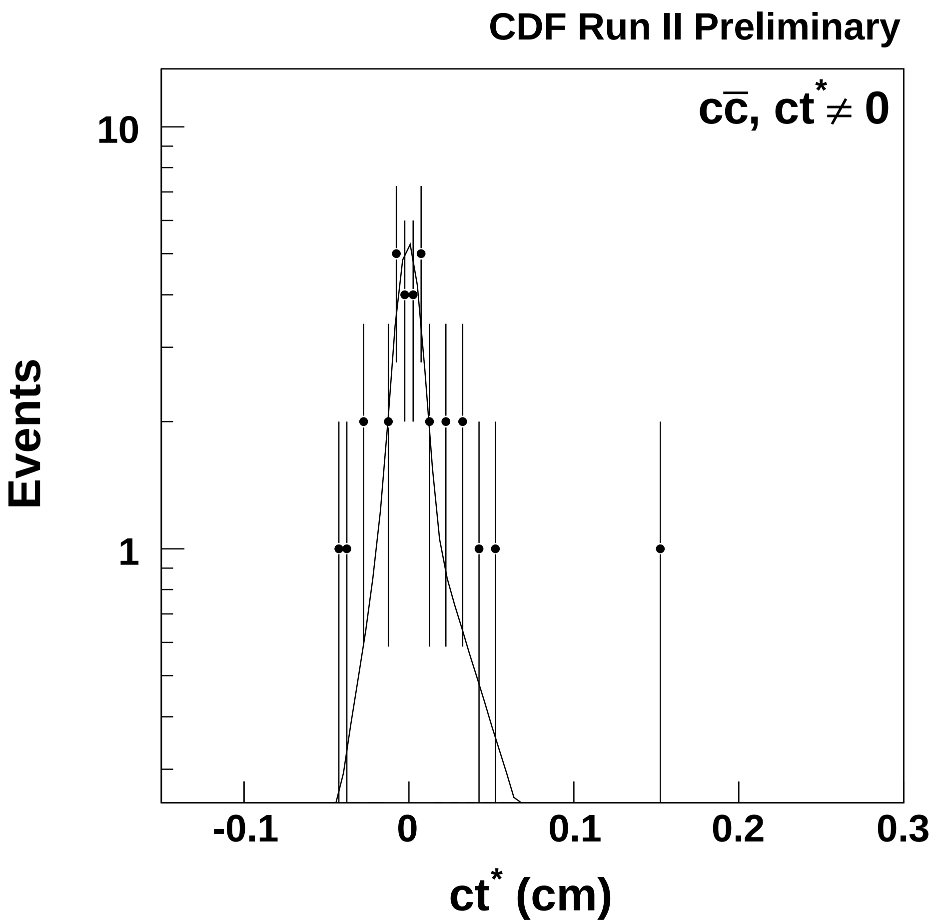
$$s = \begin{cases} 1.59 \pm 0.05 & \textbf{for muon} \\ 1.56 \pm 0.07 & \textbf{for electron} \end{cases}$$

Determination of charm BG fraction



$$f_c = \frac{N_c}{N_{D_s^+}} = \begin{cases} 3.6 \pm 4.5\% & \text{for } \mu^- D_s^+ \text{ sample} \\ 0.0 \ {}^{+7.1}_{-0.0}\% & \text{for } e^- D_s^+ \text{ sample} \end{cases}$$

ct^* **distribution for** $c\bar{c}$ **background**

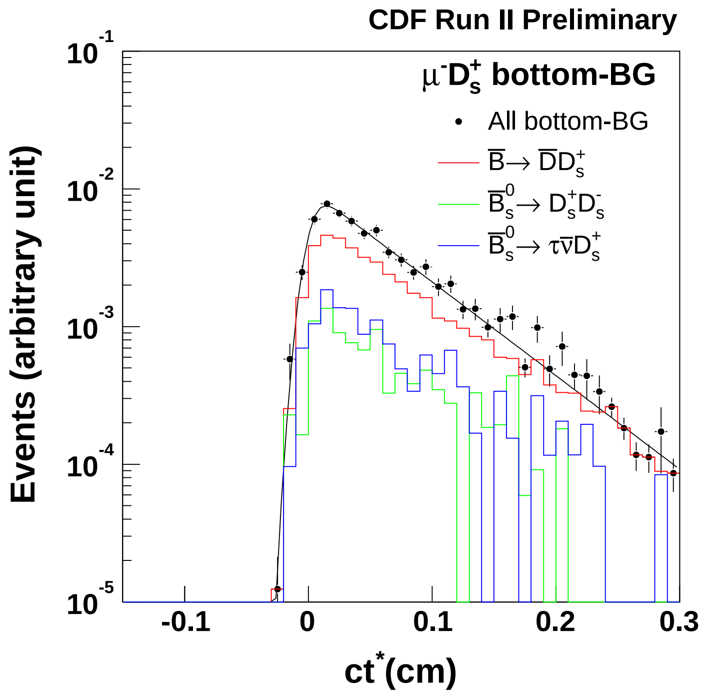


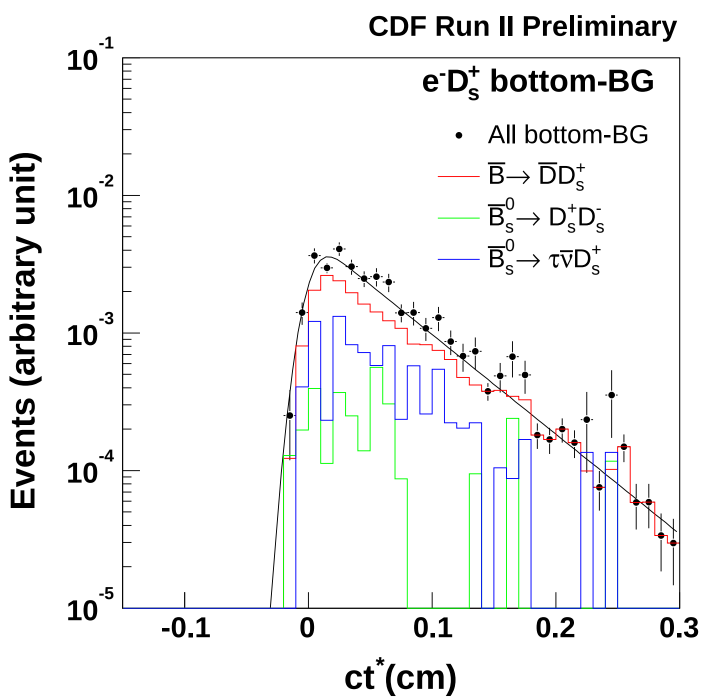
Bottom background fraction

process	N_{event} $\mu^- D_s^+$	$e^- D_s^+$
$\bar{B}_s^0 \to \ell^- \bar{\nu} D_s^+ X$	283.18 ± 2.90	264.40 ± 2.83
$B^-/\bar{B}^0 \to D_s^+ \bar{D} X$	12.77 ± 0.16	5.98 ± 0.11
$\bar{B}_s^0 \to D_s^+ D_s^- X$	2.92 ± 0.29	0.70 ± 0.14
$\bar{B}_s^0 \to \tau \bar{\nu} D_s^+ X$	4.18 ± 0.35	2.49 ± 0.28

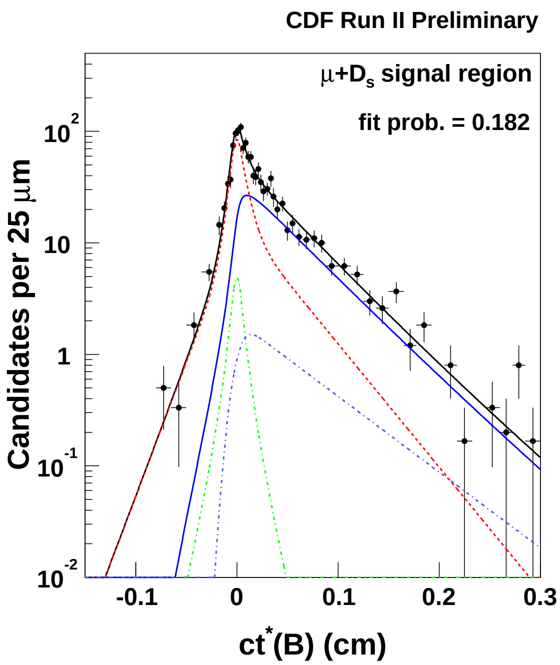
$$f_b = \frac{N_b}{N_{D_s^+}} = \begin{cases} 6.3 \pm 0.3\% & \text{for } \mu^- D_s^+ \text{ sample} \\ 3.4 \pm 0.3\% & \text{for } e^- D_s^+ \text{ sample} \end{cases}$$

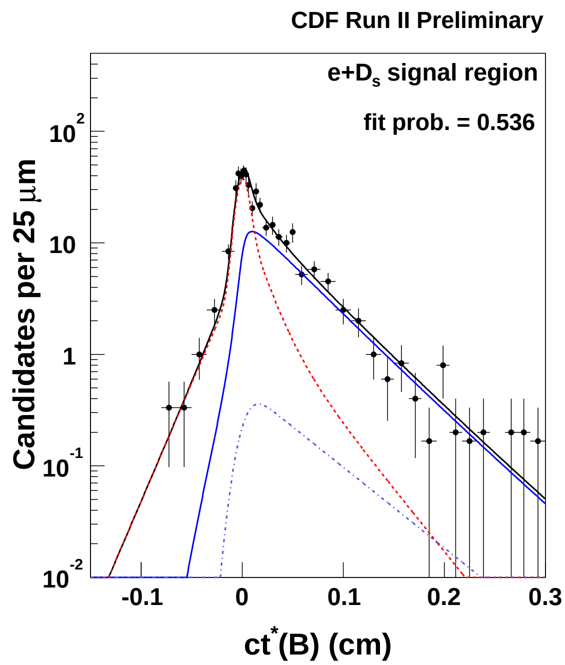
Bottom background shape





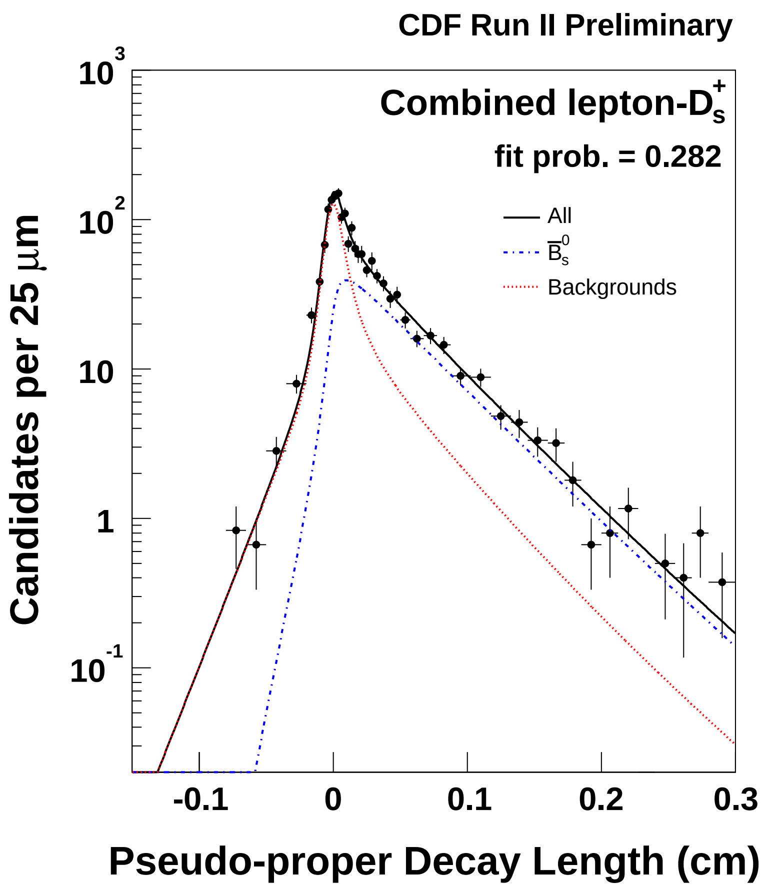
$c\tau(\bar{B}_s^0)$ fit results for muon, electron separate fit





$$c\tau(\bar{B}_s^0) = \begin{cases} 411.6 \pm 20.7\ \mu\text{m (muon)} \\ 418.4 \pm 27.8\ \mu\text{m (electron)} \end{cases}$$

Combined fit result



$$c\tau(\bar{B}_s^0) = 414.0 \pm 16.6 \ ^{+19.1}_{-14.4} \ \mu\text{m}$$

or

$$\tau(\bar{B}_s^0) = 1.381 \pm 0.055 \ ^{+0.064}_{-0.048} \ \text{ps} \ .$$

Dataset	fit probability
μ only	0.1818
e only	0.5359
Combined	0.2820

Fitting probabilities for each fit result.

Systematic uncertainties

Source	Systematics on $c\tau(\bar{B}_s^0)$ (μm)
Prompt charm background	
prompt charm fraction (f_c)	$^{+14.4}_{-6.7}$
prompt charm shape ($\mathcal{F}_c$)	± 1.5
Bottom background	
Bottom background fraction (f_b)	± 3.6
Bottom background shape ($\mathcal{F}_b$)	± 5.1
Missing momentum correction	
$p_T(B)$ spectrum	± 4.9
B decay model	± 5.0
Electron cuts	± 1.1
D_s^{**+} fraction (f^{**})	± 1.8
Signal fraction (f_{sig})	± 6.5
Resolution scale factor	± 4.0
Decay length cut	$^{+0.0}_{-2.3}$
Combinatorial background shape	± 0.2
Detector alignment	± 2.0
Total	$^{+19.1}_{-14.4}$

$\boxed{\tau(\bar{B}_s^0)/\tau(\bar{B}^0) \text{ ratio}}$

The $\tau(\bar{B}^0)$ is from previous 8 GeV $B^-/\bar{B}^0$ lifetime analysis (CDF 7458).

$$
\begin{aligned}
c\tau(\bar{B}_s^0) &= 414.0 \pm 16.6 \,^{+19.2}_{-14.4} \ \mu\text{m} \\
c\tau(\bar{B}^0) &= 441.5 \pm 10.9 \pm 16.3 \ \mu\text{m}
\end{aligned}
$$

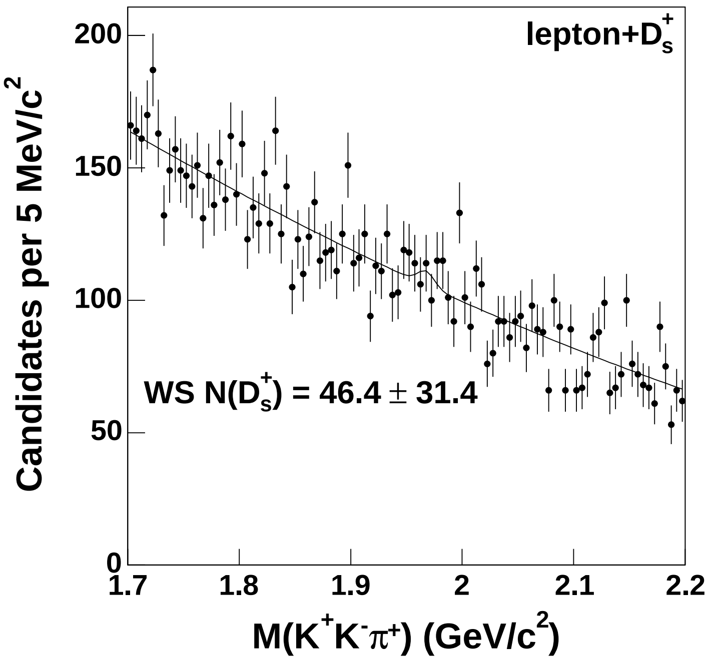
$$\Downarrow$$

$$\tau(\bar{B}_s^0)/\tau(\bar{B}^0) = 0.938 \pm 0.044 \,^{+0.050}_{-0.042}$$

Source	Systematics on $\tau(\bar{B}_s^0)/\tau(\bar{B}^0)$
Prompt charm background	
prompt charm fraction (f_c)	$^{+0.034}_{-0.019}$
prompt charm shape ($\mathcal{F}_c$)	± 0.012
Bottom background	
Bottom background fraction (f_b)	$^{+0.009}_{-0.008}$
Bottom background shape ($\mathcal{F}_b$)	± 0.012
Sample composition (affect only for $\tau(\bar{B}^0)$)	
D^{**} composition (P_V)	$^{+0.018}_{-0.023}$
π_s^+ reconstruction	$^{+0.000}_{-0.002}$
Missing momentum correction	
$p_T(B)$ spectrum	-
Electron cuts	-
B decay model	± 0.012
D^{**} fraction (f^{**})	$^{+0.017}_{-0.011}$
Signal fraction (f_{sig})	± 0.015
Resolution scale factor	± 0.004
Decay length cut	-
Combinatorial background shape	± 0.001
Detector alignment	-
Total	$^{+0.050}_{-0.042}$

Backup slides

$\boxed{\textsf{WS } \ell - D_s^+ \textsf{ signal}}$



$$
\begin{aligned}
\textsf{WS/RS} &= (1154.4 \pm 49.0)/(46.4 \pm 31.4) \\
&= 4.0 \pm 2.7\%
\end{aligned}
$$